WOOD MICROBIOLOGY

Decay and Its Prevention

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Cover photograph: The background is the surface of a hardwood board displaying the black zone lines associated with the decay of *Xylaria polymorphia* (see Figure 7-4B).

This book is printed on acid-free paper. ♾

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Preface

We believe a textbook on wood decay caused by fungi and related biologic deteriorations is needed to collect and summarize the rapidly expanding literature and experience in a single source. A need also exists to relate this information to the basic principles of biology.

It is our hope that this introductory text on the principles of decay and discoloration processes in wood will facilitate wiser use of wood resources and stimulate speculation and research in the area. We also hope it stimulates a fascination with fungi and their unique capabilities and important roles in the biologic world.

The textbook is based on a series of lectures on wood decay, its prevention, and control, presented over the past few decades to juniors and seniors majoring in forest biology or wood products at State University of New York and Oregon State University.

Emphasis is placed on the major fungal damages to wood which may develop during the growth, harvesting, storage, conversion, and use of wood for a range of major purposes. The characteristics and appearances, causes (etiology), detection, effects on various use properties, and preventions or controls are stressed.

In Part 1, Chapters 1 and 2 trace the origin and history of wood microbiology, discuss the major types of wood deterioration, and relate wood decay to the broader subject of biodeterioration. Chapters 3–5 review the general characteristics, types and classification, growth needs, and metabolism of fungi as the major cause of wood decays, and discolorations. An emphasis is placed on relating the growth needs of fungi to decay control principles. Chapter 6 summarizes key features of the structural aspects of wood and wood-moisture relationships central to fungal survival and growth in wood and the subsequent development of damaging decays and discolorations.

In Part 2, the emphasis is on the basic anatomical, physical, and chemical aspects of wood decay. Chapters 7–10 cover the basic aspects of wood decay, including types, appearances, and evidences; the anatomical and ultrastructural features of decay; decay effects on physical and strength properties of wood; and the chemical aspects of decay. Chapter 11 reviews the way fungi colonize wood and their interactions during decay development. It is a prelude to Part 3, which considers the major decay problems.

In Part 3, Chapters 12–15 review the principal decays and discolorations that may develop in wood in standing stems, during harvest, storage, conversion, and various major uses. Special emphasis is placed on the decay problems in buildings and utility poles. Chapter 16 discusses the methodologies and approaches to decay detection. Chapter 17 reviews mildew problems on wood-based coatings and related industrial problems caused by fungi and bacteria. Chapters 18–19 review decay control and prevention by use of naturally durable woods and wood preservatives. The characteristics and special uses of the major wood preservatives are discussed along with environmental concerns and restraints. In Part 4, a final chapter speculates on future decay prevention involving biological controls, new wood treatments, and developing more durable woods. An emphasis is placed on the role of biotechnology and future wood uses and modifications. Research trends and future career opportunities in wood microbiology are discussed.

The textbook is designed specifically for use in a two- or three-credit hour one-semester course. It assumes the student has had courses in general biology and organic chemistry.

The book is designed also to serve as a useful information source for wood processors, engineers, architects, and other professionals engaged in the practical aspects of wood who need to know more about the principal biodeterioration problems of a major wood use, why decay occurs, as well as how to recognize and prevent or minimize its development. It is also intended to provide some background on wood biomodifications for those interested in applying fungi for useful purposes in this period of expanding biotechnology.

The topics in each chapter are summarized to what we believe are the key essentials. The references and suggested further readings will lead interested readers to more detailed coverage of each topic.

It is a challenging and arduous task to write a textbook in the midst of an information explosion, new biologic insights, and mounting environmental concerns. Rapid advances in the related fields of mycology, physiology, genetics, electron microscopy, and biochemistry have required constant substantial revision of ideas. Yet it is the rapid changes and flux of ideas about wood decay that puts a new urgency on the need for a generalization and synthesis of the current literature for students.

Special thanks are extended to our many colleagues and associates for their encouragement, wise counsel, and assistance in reviews and improvements to the chapters. Particularly helpful to the senior author at State University of New York were James Worrall, Paul Manion, Chun K. Wang, and David Griffin. Colleagues who reviewed chapters are John Simeone

(Chapter 2—Insects as Biodeterioration Agents), Chun Wang (Chapter 3—Classifications of Fungi), David Griffin (Chapter 4—Growth Factors Affecting Fungi), James Nakas (Chapter 5—Metabolism), Wilfred C. Côté (Chapter 6—Wood Structure, Chemical, and Moisture Characteristics), James Worrall (Chapter 7—General Features of Decay), Tore E. Timell (Chapter 8—Chemical Aspects of Decay), Robert Hanna (Chapter 9—Ultrastructural Features of Decay), Dudley Raynal (Chapter 11—Colonization and Microbial Interactions in Wood Decay), and Paul Manion (Chapter 12—Stem Decays).

The authors also acknowledge the helpful comments provided by Jerrold E. Winandy, U.S. Forest Products Laboratory (Chapter 10—Changes in the Strength and Physical Properties of Wood Caused by Decay Fungi), Wayne Wilcox, University of California, Berkeley (Chapter 15—Decay Problems Associated with Some Major Uses of Wood Products), Theodore C. Scheffer of Oregon State University [Chapter 14—Wood Stains and Discoloration; Chapter 18—Natural Decay Resistance (Durability)], and Robert D. Graham of Oregon State University [Chapter 19—Chemical Protection of Wood (Wood Preservation)]. Their collective efforts significantly improved these chapters and are greatly appreciated.

Special thanks are due also to the many students in this course for their interest and innumerable sharp and penetrating questions, which placed many issues in clearer perspective.

The authors also acknowledge the assistance of Pat Spoon and Nadia Iwachiw in the typing and assembly of this manuscript, Susan Anagnost and George Snyder for a range of photographic assistance, Chris Biermann and Susan Smith of Oregon State University in the preparation of figures and chemical structures, as well as the patience of our families in dealing with this task.

As with any document, we expect that some portions will become outdated as new information becomes available. It is our special hope that this text stimulates others, much in the same way that our mentors encouraged and stimulated our interests in the field of wood microbiology.

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J. J. Morrell

CHAPTER

1

Introduction to Wood Microbiology

This textbook focuses primarily on the damaging decays and discolorations that fungi may cause to wood under some conditions of use. A major emphasis is placed on recognition, causes, conditions favoring development, effects on various wood-use properties, and preventions or controls of these serious wood defects.

This introductory chapter begins with a review of the unique qualities of wood for a wide range of uses, and the benefits of its production. This is done to put the negative defect problems that may occur in some wood uses in proper perspective. It is not too early to emphasize that when wood is properly used or handled, most wood-defect problems can be avoided or greatly minimized.

Other agents that may degrade or destroy wood are briefly discussed, because occasionally their damages can be confused with decay. Wood-decay losses at various stages of production and use are reviewed to justify the level of control effort and suggest research priorities. The historical aspects of major wood-decay understandings are traced to establish its relation to other fields, and probable emergence as a specialized facet of microbiology. The fungal cause of decay has dominated much of the early information on decay in phytopathological or mycological journals. Unfortunately, this early information on decay prevention and controls failed to reach engineering and architectural sources by whom the design of wood structures was determined. Later we shall see that the design of structures in terms of water shedding or retention can be crucial to effective decay prevention. The introductory chapter ends with some basic concepts, and the definitions of some terms that will be used throughout the book for convenience and precision.

Wood—A Remarkable Material

Wood is a remarkable material of great value and importance in the world economy. It is used extensively as a structural material, fuel, or industrial raw material in many parts of the world. It is estimated that wood currently accounts for one fourth of the value of the major industrial materials in the United States (National Research Council, 1990). As a renewable natural resource, it is available in large quantities at relatively low costs. An estimated one third of the landed area of the world is in forests. As a land crop, its supplies can be increased in both volume and quality by wise forest-management practices. Wood production in the forest ecosystem is often associated with many other forest values and amenities such as soil development and enrichment, wildlife resources, moderation and extension of water run-off, provision of superb recreational settings, reduction of atmospheric pollution, and landscape aesthetics.

Wood is also unique in a plant evolutionary sense since it was the vertical development of perennial vascular tissue (wood) that led to the aerial development of land plants. The vertical stem or trunk of the tree consists of elongated cells with unusual strength, flexibility, and durable properties at both macroscopic and ultrastructural levels. These properties permit stems to bear heavy crown loads and to withstand high horizontal stress from wind loads. The long-term selection for these properties has led to many unique properties of wood.

Wood Value and Uses

As a structural material, wood has high strength per unit weight, and is easily shaped and fastened. It is a convenient energy source and a major cheap source of cellulose and its many derivatives for the chemical industry. The color patterns and textures of woods are often pleasing, leading to uses for many decorative purposes. Wood is available in a wide range of textures, colors, densities, and chemical compositions, supporting a wide range of important uses such as construction timbers and lumber, decorative paneling, plywood, piling and wharves, railroad ties, poles and posts, packaging and crates, paper and paper products, cellulose derivatives, charcoal, and thousands of specialized miscellaneous uses ranging from pipe bowls to fiddle heads.

Potential Uses of Wood

Wood looms even more significantly as a valuable raw material in the future as expanding world populations place increasing stress on natural land ecosystems as sources for food, fiber, and energy. Modern intensive forestry practices have the potential to increase substantially both the yields and quality of wood. Trees are efficient radiant-energy transducers in many regions, and their biomass might be converted to alcohol, as alternative combustion-engine energy sources. The selective decay actions of fungi and related fermentation activities may permit the utilization of wood as a cheap source of animal feed or protein. As a material, wood is readily biodegradable under certain conditions and returns natural substances to ecosystem cycling. It has low energy requirements for conversion into various use products as compared with other structural materials. As relative raw material costs and availability change, wood has the potential to replace petroleum as the base for production of a wide range of industrial chemicals and polymers and perhaps energy itself.

Wood Disadvantages

Wood has some serious disadvantages that limit its usefulness for some purposes.

1. Wood is biodegradable, primarily by fungal action; under some use conditions, it may decay and weaken or discolor, requiring replacement. Other biologic agents also attack wood. Termites are a serious threat to untreated wood in many tropical locations. Marine invertebrates chew tunnels in wood in various salt water uses and cause serious damage. These various bioagents that can degrade or destroy wood are discussed in more detail in Chapter 2. In many cases their actions can be controlled or minimized by judicious use of treated or naturally durable wood.
2. Wood combusts at low kindling temperatures and, in certain size configurations and conditions, burns readily. Chemical treatments and wood design can reduce the combustion hazard.
3. Wood is dimensionally unstable at moisture contents below the fiber saturation point (f.s.p.) and swells as it wets and shrinks as it dries. This problem is compounded by the largest dimensional changes' occurring in the tangential plane. In round stock, such as poles or piling, the differential shrinkage often leads to deep check formation in the radial plane. Chemical treatments may reduce the dimensional changes, but these treatments are expensive. Increased use of composites should minimize any swelling or shrinkage of the wood in use.
4. Wood, as a natural product, displays considerable variability in its appearance, chemical composition, and physical properties. Some differences are the result of species or growth conditions and are mitigated by specifications. High safety factors in critical design uses of wood are used to minimize this disadvantage. Conversely, the variability in color and texture of wood provides its beauty and aesthetic appeal for many home uses.
5. Wood has a large bulk per unit weight for fuel, pulping, and chemical uses.

Effective wood handling, properly designed and maintained structures, chemical treatments, and proper use of standards and specifications can dramatically minimize these disadvantages. In a long-term environmental setting, the biodegradability of wood may minimize accumulation of the solid wastes that are created when less degradable materials such as plastics are used.

Decay Losses and Future Wood Needs

Accurate estimates of decay losses are useful to justify controls and serve as research incentives. Decay losses are difficult to quantify because of the multiplicity of wood uses under a wide range of environmental conditions. Experienced guesses are that 10% of the annual timber cut in the United States is used to replace wood that decays in service, much of it primarily from improper use and care. Added to this base raw material cost would be, in many cases, those costs representing processing, fabricating, finishing, merchandising, and assembly or replacement operations. The substantial labor costs incurred by replacement and, in some cases, the inconvenience of interrupted services would have to be added. Another subtle loss source may be eventual wood replacement by more expensive, less satisfactory materials.

Large additional supplies of wood are required to meet burgeoning population needs in the next century. A substantial first step in meeting future timber goals may be simply to handle and use wood more effectively, thereby drastically reducing decay losses. Forest pathologists and entomologists recognize that control of tree diseases and forest insect pest problems also can dramatically increase future wood supplies.

Reducing Decay Losses

Properly used wood is an amazingly durable organic material. Only a few specialized microorganisms, primarily the higher fungi, have solved the biochemical riddle of its rapid digestion.

Experts agree that much is already known about effective and economical control of decay in most wood uses. The *central control problem* is that much of this information is fragmented and not readily available or generally known by wood processors, designers, merchandisers, and users. Until recently, wood has been available at low cost, and the ease of replacement has reduced the incentive to conserve. Furthermore, the central information about wood microbiology spans many disciplines and becomes inaccessible at both academic and trade levels.

Wood Pathology versus Wood Microbiology

The subject of decays and stains in wood products has generally been referred to as either wood pathology or products pathology. Traditionally, wood decay has been considered a specialized facet of forest pathology (which is an area of phytopathology), and most forest pathology textbooks have included a chapter on wood products decays and lumber stains. This was logical and natural since forest pathology emphasized stem-decay problems and the causal fungi in its early development. This approach reflected, in part, the early emphasis of foresters on forest protection and wood harvesting and the phytopathologist's concern with fungi.

Mounting afforestation problems, epidemic diseases, and shifts in phytopathology focused the interest of forest pathology more on the disease process itself—the adverse reaction of living organisms to disease agents—and began the separation of wood biodeterioration problems from tree disease problems.

Actually, the term *wood pathology* is a misnomer; it is not a pathology at all since it deals primarily with the deterioration of nonliving materials caused by biotic and abiotic agents. *Products pathology* suffers from the same *nonliving* dilemma. Products pathology is more correctly a subject matter in phytopathology that involves the diseases of stored fruits, vegetables, and grains, which are living entities.

A more logical setting for fungal-related, wood-defect problems is *applied industrial microbiology,* which studies the microorganisms that adversely affect the properties or the appearance of food products, textiles, leathers, organic materials, paper, or wood. This field also includes substrate biomodification and fermentation by microorganisms.

We might see the emerging discipline of wood microbiology in clearer perspective by listing some closely related or overlapping fields in which information on wood decays and stains and their causal agents may appear.

1. *Phytopathology* deals with the understanding and control of plant disease, although there are some similarities between decay and tissue-disintegration disease.
2. *Forest pathology* deals with tree diseases. Some decays and stains originate in the living stem and continue as problems in the wood product; some tree pathogens are also wood saprogens.
3. *Mycology* is the study of all aspects of fungi. Most wood saprogens are fungi, although a few bacteria are also important.
4. *Microbiology* includes the study of all small organisms. It includes the diseases and deterioration they cause and all facets of their use (biotechnology).
5. *Wood preservation* is an engineering subject dealing with the physical and chemical aspects of protecting wood from fire, insects, and fungi.

The reality is that such discipline boundaries are in constant flux, and shift as need and opportunity arise. *Wood microbiology* integrates wood deterioration and wood biomodifications by microorganisms. The field should focus information on wood biodeterioration as a recognized discipline.

We shall see in subsequent chapters that much recent wood-defect literature is now appearing in wood technology and microbiology journals rather than in phytopathological or forestry journals.

Historical Perspectives of Wood Pathology

Historical awareness of a subject is important because it clearly displays the ever-evolving nature of knowledge and the occasional integration of the pieces into great unifying concepts. History also demonstrates the danger of dogma and the need for constant questioning and probing in the search for better explanations of events.

In this section, the term *wood pathology* will be used for historical reasons. Wood pathology had its origin in forest pathology, in which pathologists were interested in the nature of wood decay in tree stems, building rots, and wood storage.

A concern for wood decay and pragmatic methods to reduce this damage long preceded any recorded understanding of the cause and nature of decay. The high value of the biblical cedars of Lebanon was the result of their natural durability, important in shipbuilding and temple construction. The early Greeks knew that vertical bearing beams should rest on stone and not in direct contact with soil. Pliny, the Roman historian, recorded the susceptibility of sapwood to decay, listed durable woods, and reported that soaking wood in cedar oil reduced decay. In 1832, more than 40 years before the discovery of the true fungal nature of decay, the first successful wood-preservation process, Kyanizing using mercuric chloride was introduced in Europe. At about this time in Germany, Theodor Hartig in 1833 first recorded the microscopic appearance of fungal hyphae in decayed wood. Microscopic forms of life were then assumed to arise spontaneously from decomposition products. In 1863, Schacht reported on the effects and microscopic features of hyphae on a tropical wood; nearly 100 years later, it was recognized that his descriptions and drawings were typical of a new type of decay called soft rot. He also assumed the hyphae were the result and not the cause of the cell wall decomposition.

Forest pathology originated at the time of the settling of the great spontaneous generation versus *life from life* controversy of the mid-nineteenth century. Shortly after the classic researches of Tyndall and Pasteur had destroyed the concept of spontaneous generation and established the clear role of microorganisms in causing fermentations, the stage was set in 1874 for Robert Hartig's clear resolution of the causal relationship between the presence of hyphae and subsequent decay in wood. His early insights into the nature of decay were remarkable. He clearly connected the external fruiting body to the internal hyphae, and the hyphae and their growth on the cell walls to decay. He established later that some decays were specific for a kind of fungus and subsequently attributed these differences to enzymes. His extensive publications on wood decay and tree diseases, his cadre of students and research associates, led to rapid developments in forest pathology and wood pathology in Europe and the United States (Merrill *et al.*, 1975).

Two decades later, in 1899 in the United States, the federal government established the Mississippi Valley Laboratory at St. Louis, Missouri for reconnaissance and research on forest disease problems (Hartley, 1950). Dr. Herman von Schrenk was the initial appointee and later director of a small group. He was extremely productive and within a few years published a series of pioneer papers on the stem decays of timber species, wood decay in buildings, blue stain, preservative evaluations, and wood durability. Associated later with him in the early 1900s were G. Hedgcock, P. Spaulding, and Catherine Rumbold. Hedgcock published a classic study on chromogenic fungi that discolor wood. Spaulding contributed studies on the culturing of decay fungi and slash decomposition. Catherine Rumbold studied blue stain problems and insect roles as vectors.

At this time, the expansion of the railroads and the building program associated with the rapid western expansion of the country had led to the use of many local, nondurable woods for construction, as the supplies of durable oaks, chestnut, cypress, and cedars dwindled or were not easily available. This also was a period of increased harvesting of southern and western pines, and serious sapstain problems developed with shifts to summer air seasoning. Serious decay and discoloration problems led to concerns at the national level. One outcome was the formation of the American Wood Preservers' Association in 1904 for standardization of specifications for wood preservatives and treatments. Another was that the research of von Schrenk's group shifted increasingly to study decay of structural timbers or railroad ties and began research on sapstain control and wood preservation. At this time there was also growing concern about the threat of chestnut blight and other introduced tree pathogens.

A decision was made at the federal level to separate the forest and wood pathology programs. In 1907, the Mississippi Valley Laboratory (MVL) was discontinued, and the U.S. Forest Service's Forest Products Laboratory (FPL) at Madison, Wisconsin was assigned research responsibilities for the wood pathology program. Thus, it became the first titled program of wood pathology in the United States and has played a leadership role in wood pathology and wood preservation matters. The initial FPL research responsibilities included studies of the causes and controls of decay and stains in wood products, mycology, and the physiology of wood-products fungi, and wood preservatives. The forest pathology program was transferred to the Bureau of Plant Industry as the Office of Investigations in Forest Pathology. In 1953, it was also assigned administratively to the U.S. Forest Service.

From this beginning in 1899 in the United States, the field of wood pathology expanded steadily. Principal researchers were in the FPL, some forestry colleges, military organizations responsible for supplies, the chemical industry, and allied fields such as botany and wood technology, to name a few.

Many major contributions shaped the development of wood microbiology to the present period. In 1931, Hubert published the first American textbook on forest pathology, which contained a special section titled "Wood Pathology" and reviewed the principal research contributions of this early period. Some detail is presented here to show the rapid progress and significant accomplishments of the initial handful of dedicated researchers who defined the future course of the field. The literature sources for these early contributions are available in Hubert's Textbook cited above (1931). The major research topics with selected contributions were as follows:

1. Decay effects on wood properties such as strength (Colley, 1921) and heat conductivity (Hubert, 1924);
2. The chemical properties of decayed wood (Hawley and Wise, 1926) and the use of decayed pulpwood for paper (Rue, 1924);
3. Wood durability was attributed to soluble extractives (Hawley *et al.* 1924), and extensive durability tests on local timbers were reported (Humphrey 1916, Schmitz and Daniels, 1921);
4. The relationship of various moisture content levels in wood to decay development (Snell, 1921) and sapstain (Colley and Rumbold, 1930);
5. Decay in buildings and lumber caused by *Meruliporia incrassata* (Humphrey, 1923);
6. Decay problems and associated causal fungi in ties, mine timbers, poles, and piling (Humphrey, 1917, 1920, 1923);
7. Taxonomic studies of sapstain fungi (Hedgcock, 1906; Rumbold, 1929) and their control (Hubert, 1929); and
8. The evaluation of preservatives (Humphrey and Flemming, 1915; Richards, 1923).

In 1940, Scheffer and Lindgren completed a detailed study on the causes of lumber stains and their control. The application of their recommendations did much to minimize the serious sapstain problems of the period. In 1946, Cartwright and Findlay published their classic *Decay of Timber and Its Prevention,* which presented a worldwide summary of wood pathology information. The book was revised in 1958 and still serves as an important reference source for the field.

Davidson *et al.* (1942) and Nobles (1948) published cultural keys that greatly facilitated the identification of decay fungi isolated from timber and wood products.

In 1954, Savory established clearly that a new and significant type of decay termed *soft rot* was caused by some microfungi and Ascomycetes. The nearly century-old dogma that only Basidiomycetes can cause decay was finally dispelled. Contributions toward understanding this rot type were made by Corbett (1965), Duncan (1960), and Levy (1978). Nilsson (1973) established that substantial numbers of microfungi may cause soft rots.

In 1961, Cowling reported on the strikingly differential effects of white- and brown-rot fungi on a range of physical and chemical properties of sweet gum sapwood. Particularly significant were insights into the nature of the enzyme systems involved, based on ultrastructural dimensional restraints.

In 1965, Duncan and Lombard provided extensive information, which has been collected at the FPL over a 50-year period, on the major decay fungi associated with various wood products and wood uses, nationwide.

Verrall (1966) contributed to the understanding of decay problems in buildings in their relation to various water sources and (1965) demonstrated the effectiveness of dip or brush preservative treatments for some aboveground wood uses.

New insights into the anatomical and ultrastructural features of decay were provided by Wilcox (1970) and Liese (1970). Koenigs (1972) postulated an intriguing nonenzymatic process to explain how drastically early in the decay process, brown rot alters cell wall components in crystalline zones inaccessible to enzymes. In a decade of study, Reese (1977) and associates provided insight into the nature and action mode of the *cellulase* enzyme complex and opened the door to current commercial wood-fermentation possibilities. Eriksson (1978) clarified identities, roles, and sequences of the cellulose-degrading enzymes for a white-rot fungus. Currently Blanchette *et al.* (1987) are providing new information on the nature of decay by white-rot fungi with the scanning electron microscope.

In long-term comprehensive studies on decay origins and organism sequences in stem decays, Shigo (1967), and Shigo and Marx (1977) have demonstrated a compartmentalizing protective system in living stems, which may have major implications in subsequent wood-product treatments and use.

Butcher (1970) and Rayner and Todd (1979) have provided new insights into the sequences and many interactions of fungi in the decay process, invalidating the old concept of one fungus—one decay. Nilsson and Holt (1983) and Nilsson and Singh (1984) have shown that bacteria can cause soft-rot cavities and unusual tunnels in the secondary cell wall.

Treatments with agricultural fumigants were developed by Graham and Corden (1980) for controlling decay in poles and piling in service. Alternatives to the protection of wood by loading the cell cavities with potent toxicants are being explored increasingly as a result of growing environmental concerns. Preston (1986) has reported on new wood preservative compounds and proposed accelerated testing procedures. Rowell and Ellis (1979) have reported on chemical ways to modify wood and enhance its decay resistance.

Recent, exciting contributions by Kirk and Farrell (1987) are clarifying the enzymes in the *ligninase* system with its significant delignifying and biopulping possibilities.

Another indication of the rapidly growing interest in wood as a valuable renewable resource and its decay problems is the appearance of three books in the past several decades. Loewus and Runeckles (1977) and Higuchi (1985) edited books covering the biosynthesis and degradation of wood. Liese (1975) edited a book on the interactions of fungi and bacteria in decay development and the enzymatic mechanisms on the decay process. Nicholas (1973) edited a book on wood deterioration and its prevention that has become the most widely used book in the field. A textbook on the microbial and enzymatic degradation of wood and wood components has been prepared by Eriksson *et al.* (1990). Several comprehensive textbooks stressing the ecological aspects of wood-inhabiting microorganisms during decay development have been prepared by Rayner and Todd (1979) and Rayner and Boddy (1988).

The historical highlights of achievements in wood microbiology indicate an initial primary concern with understanding and controlling fungal damage to wood. Current trends suggest that in the future, wood microbiology will also concern itself increasingly with the beneficial uses of fungi to enhance wood properties or transform it into new products.

Concepts and Terminology in Wood Microbiology

An important part of the preparation for any profession is learning the specific vocabulary or language of that field. Terms developed to denote specific concepts, structures, or events help to simplify the complexities of the biological world, making differences, similarities, and various interrelationships more easily understood. It must be remembered that these concepts and definitions are arbitrary, and only their usefulness justifies their existence. In some cases, concepts cannot be precisely defined to include all related phenomena. Many times a series of events occurs in an intergrading series or a continuum without easy separations. In other cases, authorities simply disagree on definitions, and their conflicting views appear in the literature. The following terms will be used in this book, and an understanding of their *meaning* will be helpful in understanding the literature of wood microbiology. The terms are contrasted with their counterparts in forest pathology where applicable.

First, a clear distinction between *deterioration* and *disease* is necessary because of the forest pathology origin and current wood pathology designation of what we now prefer to call wood microbiology.

Deterioration is the destructive change in the properties of a nonliving material caused by a wide range of chemical, physical, or biotic agents. It contrasts directly with disease. Textiles, paper products, wood, plastics, and coatings are examples of wood-related organic materials that may be degraded or destroyed by biotic agents. The weakening of fabrics by the ultraviolet portion of sunlight is an example of the use of a physical deterioration agent. Corrosion of the steel beams in a bridge by salt is an example of chemical deterioration.

Disease (plant) is a sustained abnormal physiological process (or processes) of a plant or its part that may threaten the life of the plant or its parts or reduce its economic value. Disease involves reactions and changes (symptoms as responses) in the stressed living organisms, whereas deterioration concerns only changes in nonliving organic materials. Biotic or abiotic agents may instigate the changes in either case.

Biodeterioration (biodegradation) is a subset of deterioration. It is a negative term and can be defined as any undesirable change in the properties of a nonliving material caused by the activities of living organisms. The agents involved are many and varied, including bacteria, algae, fungi, invertebrates, and vertebrates such as rodents and birds. The major processes involved are *assimilation*, including invasion and digestion of organic materials such as wood or textiles; *mechanical* damage by the rasping activities of marine borers or insects; the *corrosion* of metals by the chemical activities of bacteria; and *function impairments* such as the fouling of ships' hulls by growth and accumulation of barnacles.

Two major types of wood biodeterioration, which are the central focus of this textbook, are *decay* and *discoloration* (stain). *Decay* is changes in the chemical and physical properties of wood caused primarily by the enzymatic activities of microorganisms. *Discoloration* is changes in the normal color of wood resulting from growth of fungi on the wood or chemical changes in cells or cell contents.

Other examples of materials that may be degraded or destroyed by the activities of fungi and bacteria are electrical and optical equipment, stored foods, leathers, plastics, petroleum products, textiles, and pharmaceutical products.

Biomodification is the positive term used for the biotic processes involved in the breakdown or conversion of organic or waste materials into innocuous or useful products by microorganisms. Topics of current interest are the bioconversion of trash, garbage, toxic chemical wastes, pesticides, and sewage sludges into useful products or harmless wastes. A major chemical industry utilizes fungi or bacteria to produce a wide range of chemicals and pharmaceuticals from organic materials. Great interest has also developed in the biological delignification and conversion of wood wastes into palatable animal fodders, alcohol for fuels, or yeast as protein and vitamin sources.

Fungi and *bacteria* are important destructive agents in both disease and biodeterioration. *Bacteria* are unicellular prokaryotes that reproduce by fission. *Fungi* are filamentous eukaryotes without chlorophyll that digest various carbon compounds externally. A single filament of a fungus is known as a *hypha* (plural hyphae). Collectively a mass of hyphae is commonly called a *mycelium*. Fungi reproduce primarily by spores. *Spores* are one- to several-celled units of reproduction in the fungi. They are released from the mycelium, and each cell is capable of reproducing the fungus. Biodeterioration is recognized by changes in the appearance or properties of the organic material or the physical presence of the causal agent. Disease is recognized by signs or symptoms. *Signs* are the actual physical presence of the disease-causing organism on the diseased plant. *Symptoms* are the physiological responses or reactions of the host to the presence of the disease-causing agent or organism (e.g., tissue swelling, resinosis, dwarfing). A *saprogen* is an organism that secures its food from dead materials or carbon sources. A *parasite* is an organism dependent part or all of the time on another organism of a different species and deriving all or part of its food from this living organism. A *substratum* is a nonliving organic material that serves as food to a living organism. A *host* is a living organism serving as a source of food to a parasite. A *pathogen* is an organism capable of causing a disease. Generally pathogens are parasites, but toxin-producers can be exceptions.

As we proceed through the remaining chapters, it should become clear that deterioration involves a complex array of interacting processes involving microorganisms, insects, and the environment acting on the nonliving and, therefore, nonresponsive wood substrate. This is an important concept, since the wood can not react to protect itself, and this has major implications for wood use.

Summary

- Wood has numerous beneficial properties, but is subject to degradation.
- The active study of wood deterioration dates from the late 1800s and has gradually progressed from a simple quantification of losses to more basic studies of the nature of decay.
- The term *wood microbiology* may be useful for describing the field, since it cuts across a variety of disciplines related to the decay process.

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